USING PERFORMANCE-BASED DESIGN TECHNIQUES TO EVALUATE FIRE SAFETY IN TWO GOVERNMENT BUILDINGS

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INTRODUCTION

The General Services Administration (GSA) is the business agent for the United States Government. It is responsible for the acquisition and management of everything from pencils to buildings. Within GSA, the Public Buildings Service (PBS) operates as the federal government's real property manager. In this capacity, PBS is responsible for the acquisition, design, construction, and operation and management of various types of space for federal agencies.

Currently, the inventory of space includes 1700 Government owned buildings and 5100 leased locations representing approximately 28 million square meters of space. A number of historic buildings are included in the multitude of buildings controlled by GSA. GSA real estate leasing policy gives preferential treatment to historic buildings. A recent survey of buildings indicated that the oldest building in the inventory was 180 years old.

GSA is responsible for ensuring the fire and life safety of the employees and visitors occupying the space under its control. In addition, GSA must protect federal real and personal property assets, assure continuity in the mission of occupant agencies, and provide safeguards for emergency forces if an incident occurs. Within PBS, the Office of Property Management develops the methodologies and procedures used for evaluating the safety of government occupied buildings and coordinating implementation by the GSA regional offices throughout the nation.

EQUIVALENCY CONCEPTS

Traditionally, the design of building fire safety in the United States has relied on building or fire safety code compliance. Conformance of individual building elements to specific code requirements is assumed to yield an adequate level of safety. While prescriptive-based codes are easier to enforce, design flexibility and innovation are severely limited. Typically, new code requirements are added after a disaster to prevent recurrence. Since only individual components of the total building fire safety system are addressed, the entire system never is evaluated to determine the need for previously instituted code requirements. This means that building fire protection features require an ever increasing portion of the construction budget with possibly little or no increase in safety.

In partial recognition of this, most building and fire safety codes contain equivalency clauses. These clauses permit the use of alternative methods and materials when their equivalency can be proven to the *authority having jurisdiction*. In the past, subjective judgement formed the basis for determining equivalency. Continuing research into fire phenomena has made it possible to perform an engineering analysis of the fire safety performance of a building. This building could differ widely from current perceptions of a code conforming building. Using analytical engineering tools, the development and impact of fire in a building can be assessed. Recommended improvements can be prioritized based on their predicted impact on the risks associated with potential fire exposure.

The United States Congress included an equivalency option in the Federal Fire Safety Act. This Act, passed by Congress and signed by President George Bush in 1992, is part of the Fire Administration Authorization Act (Public Law 102-522) [1]. The Federal Fire Safety Act requires sprinklers or an *equivalent level of safety* in all new six story or higher Federal Employee Office Buildings, and requires upgrades during renovations of such buildings if they are six stories or higher and the renovation is more than 50 percent of the value of the structure. In addition, when the Government leases 3,250 total aggregate square meters or more of space and any portion is on or above the sixth floor, the entire building must be protected with sprinklers or an *equivalent level of safety*. A "Federal Employee Office Building" is defined as any building, owned or leased by the Federal Government, that can be expected to house at least 25 Federal employees during the course of their employment.

The General Services Administration was required by the Act to issue regulations further defining the term *equivalent level of safety*. In developing the regulations, GSA held meetings with a working group composed of representatives from the United States Fire Administration, the National Institute of Standards and Technology, and the Department of Defense as well as a number of other affected federal agencies, trade associations, state fire marshals, fire chiefs, consulting engineering firms, building owners, academia, and research institutions. The final regulation was established in the form of a performance requirement [2]. A fire protection engineering analysis is used to measure hazard and the amount of protection provided by the building. The concept for the final rule was derived from GSA fire protection program philosophy and built upon the equivalency concept contained in building and fire safety codes.

RISK MANAGEMENT

Typically, government agencies in the United States do not have insurance like private sector building owners or occupants. Any loss that occurs must be paid out of an agency's operating budget. A single loss could severely impact an agency's ability to conduct nationwide operations. Building and fire codes are intended to protect against loss of life and limit fire impact on the community. These codes do not necessarily protect the assets of the building owner or occupant. Simple code compliance does not ensure a level of safety acceptable to the building owner or occupant. The continual search for code compliance is not sufficient justification for resource allocation.

With cost effectiveness in mind, the GSA fire protection program addresses all aspects of fire safety important to a building owner or occupant (life safety, property protection, and mission continuity). To ensure adequate levels of safety, the relationship between expenditures on fire safety and the actual impact of these expenditures is examined through technical analysis. Each building in the GSA inventory is subjected to a fire safety analysis every five years. These building surveys are conducted by fire protection engineering professionals.

A critical step in the evaluation of a building's fire safety performance is identification of a set of design fires. These fires are ones that could produce severe affects on the building and its occupants. Full scale testing of fuel packages, analysis of fire loss statistics, and professional judgment are used to establish the set of design fires. Using the design fires and building characteristics, potential fire scenarios are modeled to determine the effects on life safety, property, and mission. Based on this professional analysis, actual risk conditions in each building are identified and corrective actions recommended. As necessary, building owners allocate resources to abate significant risks.

RESEARCH ACTIVITIES

In support of its risk management philosophy, GSA has sought to look beyond the codes and standards for methods that would allow technical assessment of building fire safety risks and development of necessary solutions. GSA professional staff have been involved in the development of various alternative methods of analyzing life safety such as system concepts [3] and National Fire Protection Association Standard 101A, *Alternative Approaches to Life Safety* [4].

In addition, significant resources have been devoted to the development of life safety alternatives through scientific research. GSA has focused its research activities in three major areas: model development and verification, suppression system effectiveness, and protection of mobility impaired persons. The development of *FPETool* [5, 6] was a significant result of these research activities. Using this package of analytical engineering tools, the development and impact of fire in a building can be assessed. GSA has integrated the use of *FPETool* into its design review and facility assessment processes for evaluation of fire risk in GSA controlled space and appropriate resource allocation.

APPLICATION

As part of the NIST effort to continue development of the Fire Safety Assessment Methodology, two buildings were selected for application of the performance-based design techniques. The buildings represent a cross section of the GSA inventory. Each building contains a mixture of occupancy groups including business, assembly, and storage. Both buildings are highrises according to U.S building codes and are being considered for renovation in the next 5 to 10 years. Results from these fire safety assessments will be used to plan the renovations.

John W. Peck Federal Building

The first building selected for analysis was the John W. Peck Federal Building, located in Cincinnati, Ohio. This building, constructed in 1963, has ten floors above grade, a basement, and a sub-basement. The building provides approximately 6,178 gross square meters (66,500

ft^2) of space per floor. A typical floor plan is shown in Figure 1. It is occupied primarily as office space for a number of Federal agencies. A day care center is located on the first floor, a cafeteria is located on the second floor, and a credit union is located on the fifth floor. Computer rooms are located on floors 2, 4, 6, 7, and 9. The sub-basement and basement levels are occupied by a parking garage and mechanical equipment rooms.

The building is a fire resistive structure with limestone exterior walls, reinforced concrete floors, and a reinforced concrete roof. Interior partitions are mainly gypsum board or concrete block with some hollow tile walls. The interior finish is primarily painted plaster and gypsum board.

Egress from all floors is accomplished through six stairwells. Each stair is enclosed by a shaft of masonry construction with openings protected by 1 ½ hour fire rated doors. All of the stairs discharge within unprotected corridors and lobbies on the first floor. The second floor also serves as a level of exit discharge via a sprinkler protected skywalk leading to another building.

The sub-basement paint shop, most of the basement, first floor storage area, the day care center, skywalk, second floor south wing, and computer rooms on the sixth and seventh floors are protected by wet pipe sprinkler systems. These systems are reportedly designed by pipe schedule for ordinary hazard occupancies. The sprinklers are fed by a six inch combination sprinkler/standpipe riser located in each stair. Each riser is equipped with 63.5 mm (2 ½ in) hose valves located in the stair at each floor level. The system pressure is boosted upon demand by a fire pump rated for 3,785 lpm (1000 gpm) at 690 kPa (100 psi).

The building is equipped with a fire alarm system designed to provide selective evacuation. Occupants on the appropriate floors are notified of alarm conditions by taped voice messages over speakers located throughout the building. The speakers can also be used for live voice communication during emergencies. Occupants of the fire floor are instructed to relocate one floor below. Occupants of the floor above the fire are instructed to relocate two floors down. Occupants of the floor below the fire floor are warned of the fire emergency and are instructed to expect the occupants of the two floors above. Alarms are initiated by manual pull stations located at each exit and stair door, sprinkler flow switches, duct smoke detectors, and computer room smoke detectors. Each floor is equipped with telephones for use by floor fire wardens or the fire department. Fire alarm signals are transmitted to a central station receiving service.

The building has 13 elevators, 12 passenger and one freight. Smoke detectors located in the elevator lobbies as well as activation of any fire alarm device except for first floor devices initiate automatic recall of the elevators to the first floor. Activation of first floor devices recalls elevators to the second floor. All elevators have fireman's capture and contain emergency telephones.

Evaluation of the existence of an equivalent level of safety was one objective for the analysis identified by the building owner (GSA). According to the equivalent level of safety regulation [2], an analysis must indicate that the existing and/or proposed safety systems in the building provide a period of time equal to or greater than the amount of time available for escape in a similar building complying with the requirements of the Federal Fire Safety Act of 1992. In conducting an analysis, the capability, adequacy, and reliability of all building systems impacting fire growth, occupant knowledge of the fire, and time required to reach a safe area must be examined. In particular, the impact of sprinklers on the development of hazardous conditions in the area of interest must be assessed.

Typically, so-called "standard sprinklers" would be used in office type occupancies. This type of sprinkler would not necessarily provide the level of life safety required in the Act [7]. The use of quick response sprinklers would be required to achieve the appropriate level of safety. Therefore, the baseline analysis must be related to a building equipped with quick response sprinklers and standard response sprinklers.

Three options for establishing an *equivalent level of safety* are provided in the regulations. In the first option, the margin of safety provided by various alternatives is compared to that obtained for a code complying building with complete sprinkler protection. A second alternative is applicable for typical office and residential scenarios. In these situations, complete sprinkler protection can be expected to prevent flashover in the room of fire origin, limit fire size to no more than 1 megawatt (950 Btu/sec), and prevent flames from leaving the room of origin. As a third option, any other technical analysis procedures could be used to show equivalency subject to appropriate approvals.

The margin of safety is the difference between the available safe egress time (ASET) and the required safe egress time (RSET). Available safe egress time is the time available for evacuation of occupants to an area of safety prior to the onset of untenable conditions in occupied areas or the egress pathways. The required safe egress time is the time required by occupants to move from their positions at the start of the fire to areas of safety. Available safe egress times would be developed based on an analysis of a number of assumed reasonable worst case fire scenarios including assessment of a code complying, fully sprinklered building. Additional analyses would be used to determine the expected required safe egress times for the various scenarios. If the margin of safety including an appropriate safety factor is greater for an alternative than for the fully sprinklered building, then the alternative should provide an *equivalent level of safety.*

$$\text{Margin of Safety} = \text{ASET} - \text{RSET}$$

$$\text{ASET} \geq \text{Safety Factor} \times \text{RSET}$$

$$\text{ASET}_{\text{alternative}} \geq \text{ASET}_{\text{sprinkler}}$$

A number of engineering tools are available for developing information to support an *equivalent level of safety* analysis. The first tool used in this analysis is the fire safety evaluation system (FSES) which is documented in Chapter 7 of National Fire Protection Association (NFPA) 101A, *Guide on Alternative Approaches to Life Safety* [4]. The FSES indicates that the building does not provide a level of safety equivalent to the current requirements for existing business occupancies (Chapter 27) contained in NFPA 101®, *Life Safety Code®* [8]. The development of the FSES has lead to the inclusion of some inconsistencies in the document. While the *Life Safety Code®* provides an option for existing high rise office buildings to be protected using a "life safety system", this concept is not included in the FSES. Any unsprinklered high rise building will fail the existing version of the FSES. Since GSA typically requires an FSES for each building fire safety analysis, it is included here primarily for completeness. At some point in the future, the FSES may be updated to allow for the evaluation of unsprinklered or partially sprinklered high rise buildings.

Fire modeling is another useful tool for determining *equivalent level of safety*. A fire model called FASTLite [9], developed by the Building and Fire Research Laboratory at the National Institute of Standards and Technology, was used to estimate the rate of development of hazardous conditions within the building for certain fire scenarios. This model is the successor to *FPETool*. In order to use fire modeling, the expected fire growth rate must be identified and provided as input data for the model. Research conducted by NIST for GSA indicates typical office building fuel packages produce heat release rate time histories which grow at a medium rate proportionally with time-squared.

$$\dot{q} = \alpha t^2$$

Specifically, three-sided office work stations were shown to produce heat release rate curves approximating a medium growth rate, $\alpha = 0.0117$ kJ/s^3 (Figure 2). This so-called medium growth rate fire has been documented and used in NFPA 72, *National Fire Alarm Code* [10], for establishing heat and smoke detector placement requirements. A medium growth rate fire was used in the analysis discussed here.

Using the medium growth rate fire, several fire scenarios were identified based on a site visit and review of the previous fire safety reports. Fires were assumed to occur in either a typical office (7.6 m x 6.1 m x 3 m) or an open plan area (30.5 m x 15 m x 3 m). Calculations were performed assuming the door to the fire room was either open or closed. The fires were allowed to grow until the space reached flashover or the fire became oxygen starved. The fire could become oxygen starved from either the ventilation limitations of the space or immersion in the oxygen depleted upper layer. The heat release rate followed the medium growth rate fire curve for at least the first seven minutes of each simulation regardless of room size. Using the fire model, the impact of the fire on an attached corridor and adjacent room was examined.

The times available for safe egress are summarized in Table 1. The columns labeled "office" and "open plan" present calculation results for fires occurring in the office space or the open plan space, respectively. On average, the calculations indicate that without sprinkler protection a fire will produce untenable conditions or otherwise begin to compromise the egress system in about five minutes after the start of open flaming.

As a point of reference, the NFPA Fire Protection Handbook lists survivable condition criteria if a sprinkler is to provide life safety [11]. Gas temperatures at eye level (1.6 m (5.25 ft) above the floor) cannot exceed 93 °C (200 °F). The maximum allowable ceiling temperature is 260 °C (500 °F). Finally, carbon monoxide concentration cannot exceed 0.15% by volume. The assessment of other potentially toxic effects, such as from heat flux or toxic gas interactions, was not addressed in this analysis. As can be seen in Table 1, standard response sprinklers do very little to improve the situation because of their relatively long activation time. The best improvement is obtained using quick response sprinklers (RTI 40 $(m\text{-}s)^{1/2}$). The use of quick response sprinklers prevents development of hazardous conditions in all of the modeled cases.

Table 1. Times in Seconds for Sprinkler Activation and Untenability

Sprinkler Type	Activation Time (s)		Time to Untenability (s)			
			Office	Open Plan	Corridor	
	Office	Open Plan			Office	Open Plan
None	X	X	180	300	360	400
Standard	260	425	180	300	∞	400
Quick Response	171	299	∞	∞	∞	∞

The second step in conducting the *equivalent level of safety* analysis is determining the time required to move building occupants from the vicinity of the fire to an area of safety. Several models which use hydraulic flow approximations are available for estimating egress time. The FASTLite suite of programs includes an egress model. This model was used to examine the required egress time. Results of the egress time calculations are shown in Table 2.

Several variables were evaluated including number of occupants and number of available egress paths. An occupant load per floor of 650 people is obtained using the occupant load factor specified in the *Life Safety Code®*. Each floor is expected to hold approximately 300 people using the GSA specified occupant load for the building. Examination of a typical floor layout (Figure 1) suggests the possibility that a single fire could block at least two of the six exits. Therefore, calculations were performed assuming the availability of six exits and four exits. Depending on the assumption, the results indicate two to five minutes would be required for all people on the fire floor to move to an area of safety. For this analysis, the area of safety was assumed to be the floor below the fire. Additional calculations indicate that it would require an additional 60 seconds for people to evacuate from the floor above the fire (move down two floors).

Table 2. Summary of Calculated Egress Times in Seconds

Number of Exits Available	Number of Occupants	Time to Clear Floor	Time to Move One Floor
6	300	70	90
	650	150	200
4	300	100	140
	650	220	290

Typically, the selective evacuation system used in this building is not considered appropriate for an unsprinklered building. Therefore, it is possible that areas within the building would not remain "safe areas" during the course of a fire. Additional calculations indicate that it would require approximately four minutes for people on the tenth floor to move to ground level. As a factor of safety, it is recommended that the egress times calculated in this analysis be doubled [12]. The egress calculations assume the occupants are readily mobile and will begin leaving the building immediately upon notification. A factor of safety more than double could be appropriate for addressing issues such as delayed notification, limited mobility, and other factors.

In this analysis, the available and required safe egress times are almost equal for an unsprinklered building. Typical engineering practice requires that some margin of safety be included to address reliability and variability. One factor of safety was included in the egress analysis where evacuation time was calculated assuming one-third of the exits were blocked. However, additional safety factors should be included in the final assessment to address various uncertainties. Safety factors can be applied in the form of an increase or decrease in the design fire size, an increase or decrease in the fire growth rate, a conservative estimate for a performance criterion, or an increase in the estimated travel time used in egress calculations [13]. The application of additional safety factors would decrease available safe egress time and increase required safe egress time. Therefore, it can be concluded that the building as it currently exists does **NOT** provide the equivalent level of safety described in Public Law 102-522 or 41 CFR 101-6.6.

In a building with complete sprinkler protection, the sprinklers would probably activate to control the fire and limit development of hazardous conditions. In the specific case of the Peck building, the calculations indicate standard response sprinklers would be of little or no benefit to people located on the floor of fire. However, the standard sprinklers would provide protection for people not located on the floor of origin. This is one reason why selective evacuation is used in fully sprinkler protected high rise buildings. It is also evident from the calculations that the use of quick response sprinklers would greatly enhance the protection of occupants on the floor of fire origin as well as the other floors in the building. In addition to enhancing life safety, the use of quick response sprinklers would limit property damage and help minimize downtime if a fire occurs.

Department of Justice Main Building

The Department of Justice Main Building is the other building selected for analysis. This seven story office building, located in Washington, DC, was built during the 1930s. This building is listed on the National Register of Historic Places. It is constructed of reinforced concrete supported by steel framing system of beams and columns. Many of the stairs are open on one or more sides exposing them to elevator lobbies and the remainder of the building. Some portions of the building are currently protected by automatic sprinkler systems. Many of the offices contain substantial amounts of wood paneling and trim. As expected in this type of occupancy, security issues are a significant concern and must be balanced against fire safety. The analysis of this building is continuing and will not be presented in this paper.

INNOVATION INCREASES SAFETY

Through the use of the Fire Risk Assessment Methodology and *FPETool*, GSA is implementing a performance-based system of building design and assessment. This methodology enables GSA to rapidly apply the knowledge gained from its research activities in practical applications.

The National Institute of Standards and Technology and GSA continue to work together to expand the science of fire protection. Optimal utilization of sprinklers is a key component in most fire protection strategies. Efforts are underway to further evaluate sprinkler response and improve their application.

In order to use most fire models like *FPETool*, heat release rate data must be available. A catalog of heat release rates for typical office furnishings is being developed. In addition to the data required by the models, this catalog will include video footage of the fire tests and still pictures of the tested items. Finally, validation of the *FPETool* fire model and its subcomponents is an on-going effort.

CONCLUSION

Significant advances in the scientific understanding of fire have occurred over the last several years. These advances have resulted in the development of a number of engineering tools for measuring building fire performance. However, the application of these tools remains limited because there is no widely accepted framework in which to apply these tools. Building and fire codes simply state that equivalency based on performance is possible without giving any guidance on how it is to be judged.

Currently, work is underway to develop a framework in which to utilize performance-based equivalency. The results of this effort will foster the application and acceptance of fire protection engineering analysis tools. By designing to meet the expected fire challenge and not the specific code book requirements, appropriate levels of fire safety can be provided in buildings while increasing flexibility and potentially reducing costs.

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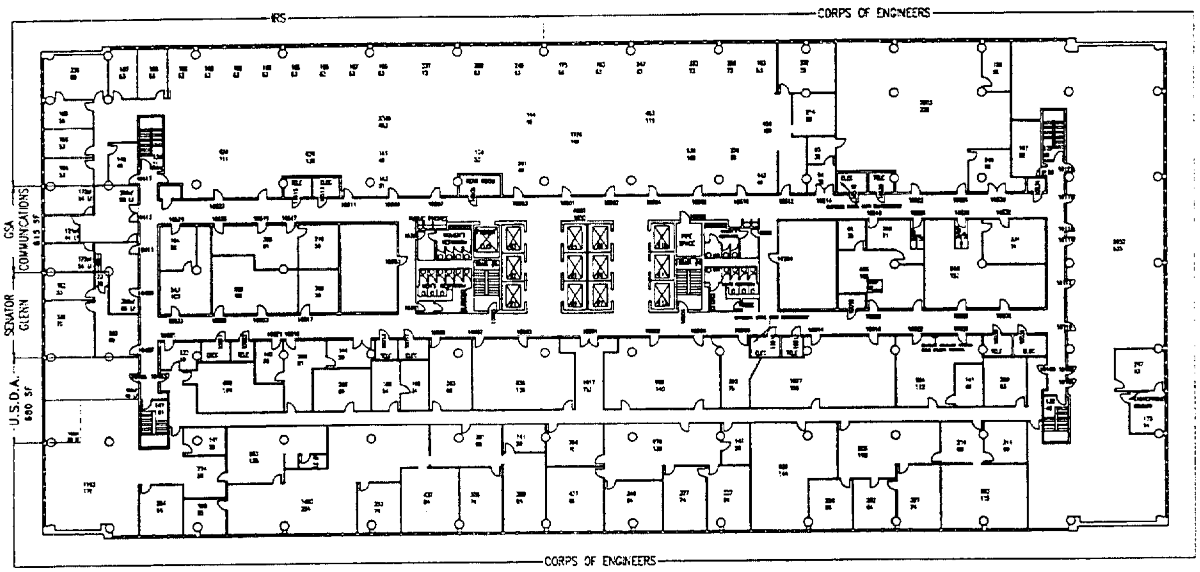

Figure 1. John W. Peck Federal Building Typical Floor Plan

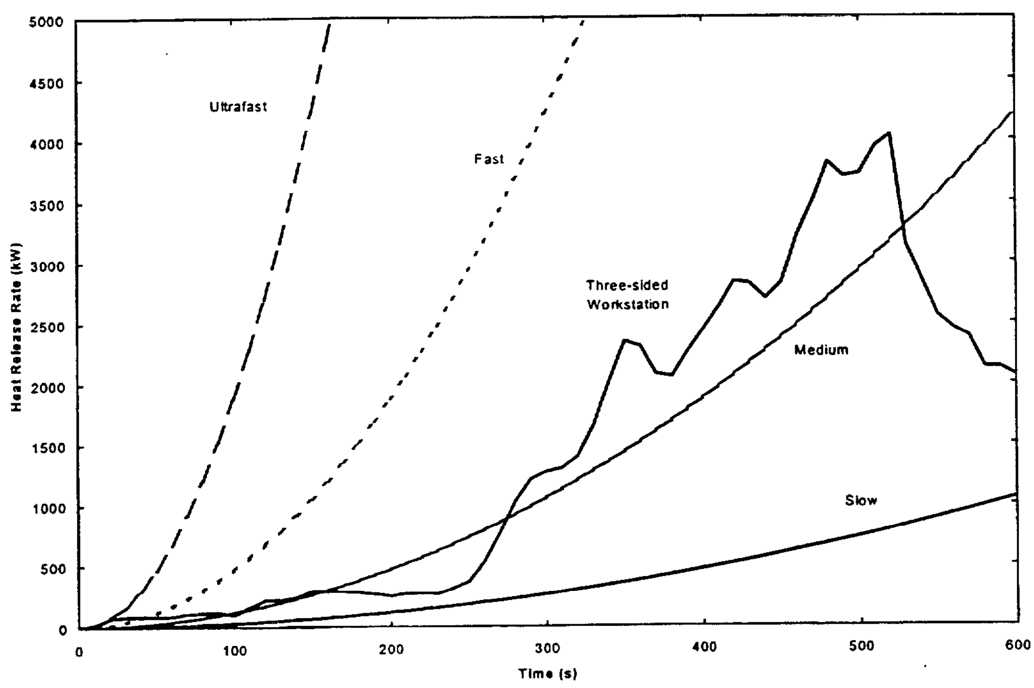

Figure 2. Comparison of "t-squared" and Workstation Heat Release Rates